POSITIVE AND NEGATIVE INFLUENCES OF HYDROELECTRIC PLANTS ON DRAVA RIVER TO GROUNDWATER QUALITY

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Abstract: At the confluence of the Drava and Mura river there is spacious lowland where a significant gradient of the Drava river is preserved. Such conditions were favourable for construction of three hydroelectric plants along the total of 60 kms of the Drava watercourse in Croatia from the Slovenian border to the mouth of the Mura River. Marginal conditions of phreatic aquifer were strongly affected by construction of the three mentioned hydroelectric plants. The formed accumulation lakes caused ground water recharge and elevation of the water table, and on the other side, drainage channels were cut deeply into the aquifer, which resulted in strong ground water drainage. In this paper, changes in nitrate content of the groundwater from the two most important well fields in the area are considered. Upon construction of the upstream dam, the nitrate content in both well fields was increased from approximately 2 to over 20 mg N/l. The principal cause for this is found in expansion of the drainage area in the region with intensive agriculture and reduction of the groundwater recharge from the Drava River. After the second dam was completed, the nitrate content in one of the well fields was gradually diminished to under 5 mg N/l, mostly because of the increased recharge from the newly formed accumulation lake, which is interpreted as an illustration of the possibly positive influence of construction of hydro-electric power plants.

Key words: phreatic aguifer, groundwater quality, hydro-electric plants, hydogeological condition.

POSITIVE UND NEGATIVE EINFLUSS DES WASSERKRAFTWERKES AUF DER FLUSS DRAVA ZU GRUNDWASSERQUALITÄT

Zusammenfassung: in der Wasserlauf des Flüsse Drava und Mura verbreitet sich eine unermessliche Tal, wo sich dauernd eine bedeutende Gefälle zu dem Fluss Drava abhaltet. In solchen bedingungen, war es möglich drei Wasserstiege, insgesamt 60 km des Flusses Drava in der Republuk Kroatien entlang, bis zur grenze mit der Republik Slovenien und Mündung des Flusses Mura, zu formen. Die Bordbedingungen des Wassertragende haben sich stark durch den Wasserstiegeausbau vorändert. Die Speicherseen haben das Wassersteigung des Grundwassers und Vergrösserung der Wasserfläche induziert. Ableitungskanäle sind tief in Wassertragend eingeprägt und haben eine starke Entwässerung des Grundwassers verursacht. In der Artikel sind die Veränderungen des Nitratinhalts im Grundwässer der zwei bedeitendsten Grundwasserförderungsgebieten dieses Gebietes ilustriert. Auf beiden Grundwasserförderungsgebieten ist die Nitratinhalt nach dem Oberwassersteigaufbau von 2 mg N/l aufs mehr als 20 mg N/l aufgesteigt. Der grösste Anlass dass es zu diesem Stand gekommen ist, und die Reduktion der Grundwassersteigung aus der Fluss Drava. nach der Aufbau der nächte Wasserstieg, hat sich die Nitratinhalt auf eine Grundwasserförderungsgebiete sukzessiv unter 5 mg N/l verringen. Das war vor allem unter Einwirkung des induzierten Wassersteigung aus demm neuen Speichersee. das zeigt uns dass es möglich positive Wirkungen der Wasserstiegaufbau gibt.

Schluesselworte: Wassertragend, Grundwasserqualität, Hydrozentrale, Hydrogeologische Bedingungen

1. Introduction

Upstream of the confluence of the Drava and Mura rivers (Figure 1) there is a spacious valley of the town of Varazdin, where over 100 m thick gravely and sandy sediments were deposited, thus forming the phreatic aquifer which is important for local and regional water supply. This is also the area of the largest gradient of the Drava River watercourse through Croatia, which enabled construction of the three hydroelectric plants positioned over a total of 60 kms of the Drava watercourse from the Slovenian border down to the Drava/Mura confluence.

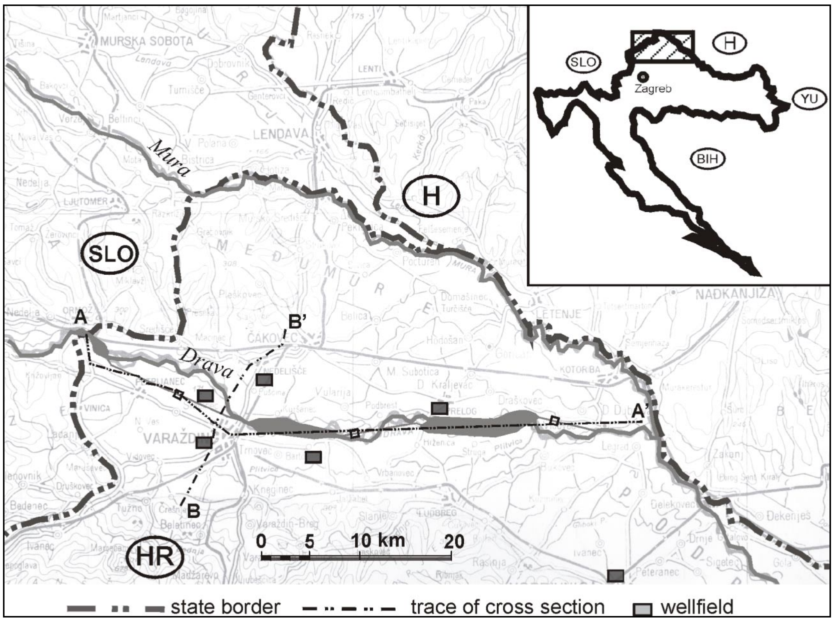

Figure 1. Situation map.

All three hydroelectric plants have an accumulation lake from which the water is transported by a channel to the engine room. Downstream of the engine room, there is a deeply incised discharge channel, which takes the water either to the second (downstream) accumulation lake or to the old watercourse of the Drava River. Such construction of hydroelectric plants caused a strong influence to the groundwater of the Varazdin aquifer. Accumulation lakes have elevated the groundwater level in some sections, while the drainage influenced by the deeply incised discharge channels resulted in lowering of water table in other regions.

Such a change of the marginal conditions of aquifer influenced the groundwater quality, too, because it resulted in change of the degradation of groundwater quality caused by intensive agricultural activity.

2. Hydrogeological conditions

The Drava River valley upstream of the Mura River mouth pertains to the geotectonic unit of the marginal part of the so-called Mura depression. Eastern margin of this tectonic unit is the Legrad horst, which separates the Mura depression from the Drava depression in the east. The youngest (Pliocene-Quaternary) tectonic events in this area resulted in final formation of mentioned structures and profoundly influenced sedimentation of Quaternary layers wherein the Varazdin aquifer was formed.

During Quaternary (esp. Holocene) in the Varazdin area of the sedimentary basin, mostly coarse gravels were deposited, containing various percentages of sand and reaching over 100 m in thickness (Figure 2). Simultaneously, along the SE margin of the Legrad horst there was a rapid subsidence of the Drava depression, which was also being filled with gravels and sands. The only difference in this region is in reduced size and proportion of gravel pebbles and increased proportion of sand-sized particles and of the fine-grained clastic sediments as well.

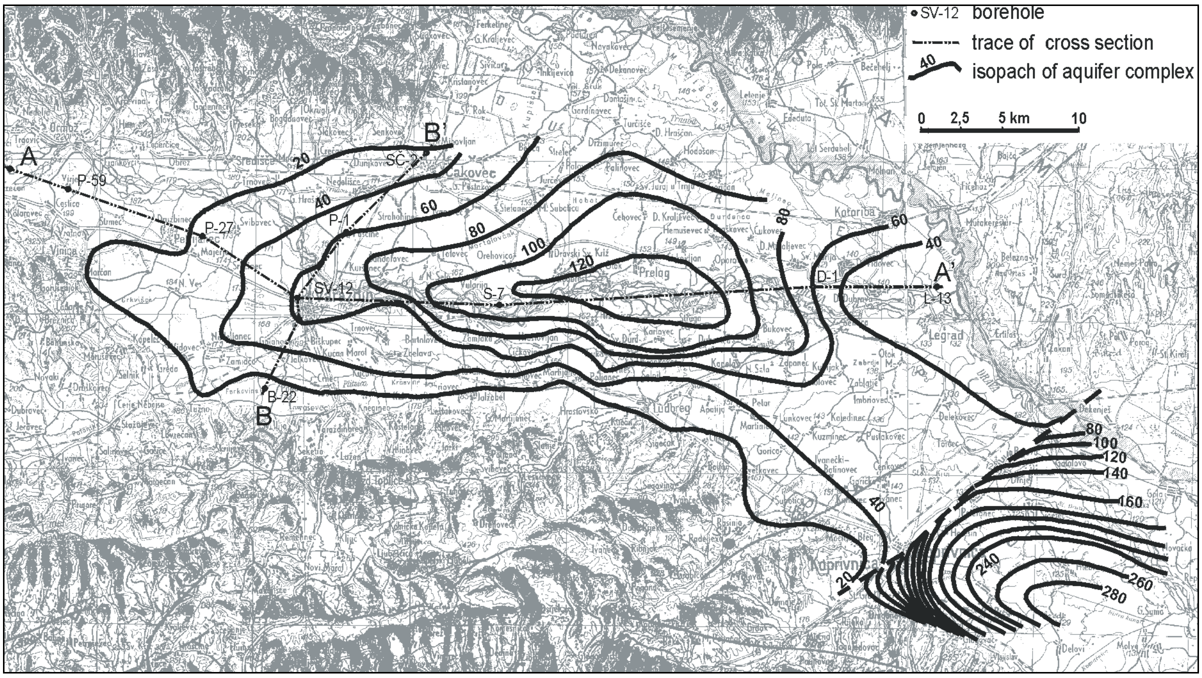

Figure 2. Isopach map of the aquifer

Gravely and sandy sediments that were deposited in the spacious Drava river valley of the Varazdin basin have influenced the formation of the Varazdin aquifer. These gravely sediments are most likely of the Middle to Late Pleistocene and Holocene age. Fine-grained fractions (clay, silt and silty sand) are sporadically encountered, having mostly the form of thin lenses and interbeds. The aquifer is elongated roughly parallel to the general direction of the Drava River course and is gradually thickening from west to east. Its lateral boundaries lie along the rim of surrounding hills and are in most cases coinciding with faults.

Aquifer has minimal thickness in the western part of the study area, where gravely Quaternary sediments cover a subsided anticline (Figure 2). The aquifer structure in this region is asymmetric in respect to underlying sediments. Along the Drava River course, the aquifer thickness equals only 5 m, so the riverbed cuts through the entire thickness of aquifer (Figure 3). Thickness of gravely sediments is increasing in eastern direction, and reaches 70 m in the area of the Varazdin well field, and 100 m in the area of the Bartolovec field. In the central part of depression, the thickness of Quaternary gravely sediments exceeds 120 m. Clay, silt and silty sand were drilled in the base of gravely sediments. Shape of sedimentary bodies of the water-saturated gravels is illustrated in lithological cross-sections (Figure 3).

The granulometric composition of the water-saturated sediments is dominated by gravel pebbles with various proportion of sand. There is a general trend of reduction of the size of pebbles and sand grains from west to east, but there are some local anomalies as well. Lenses of clay and sand are very rare, with exception of a regionally important mixed clay, silt and sandy silt interbed which was drilled in numerous wells in the broader surroundings of Varazdin. Thickness of this layer isn't large, it seldom exceeds 5 m, and can locally be less than 1 m thick but is usually between 2 and 6 m. In some regions, this clayey layer is thinned out, but it nevertheless makes a significant regional discontinuity of depositional environment. It can therefore be stated that a regional semi-permeable interbed exists and divides the gravely aquifer in two water-saturated layers.

The water system consists of two water-saturated layers. The upper one is a phreatic aquifer in which the Drava and Mura river courses are incised which means that its marginal conditions are strongly governed by the marginal conditions induced by construction of hydro-electrical plants. Its thickness seldom exceeds 50 m and is much more uniform in comparison with the underlying aquifer (Figure 3). Hydraulic conductivity of the upper water-bearing layer is roughly in the range of 1-4 mm/s, while lower layer has 1 mm/s. The leakage coefficient through the semi-permeable layer between the upper and lower aquifer is 10^{-3} $days^{-1}$.

Altogether 6 well fields (Figure 1) are used for exploitation of groundwater for the water supply. The largest well fields are named Varazdin and Bartolovec (Figure 4) and they are the bases for the Varazdin water-supply system. All well fields are exploiting the phreatic aquifer except the Bartolovec well field which is built in such a way that 2 wells exploit exclusively the upper, phreatic aquifer, and another 2 wells are producing only from the lower, leaky aquifer.

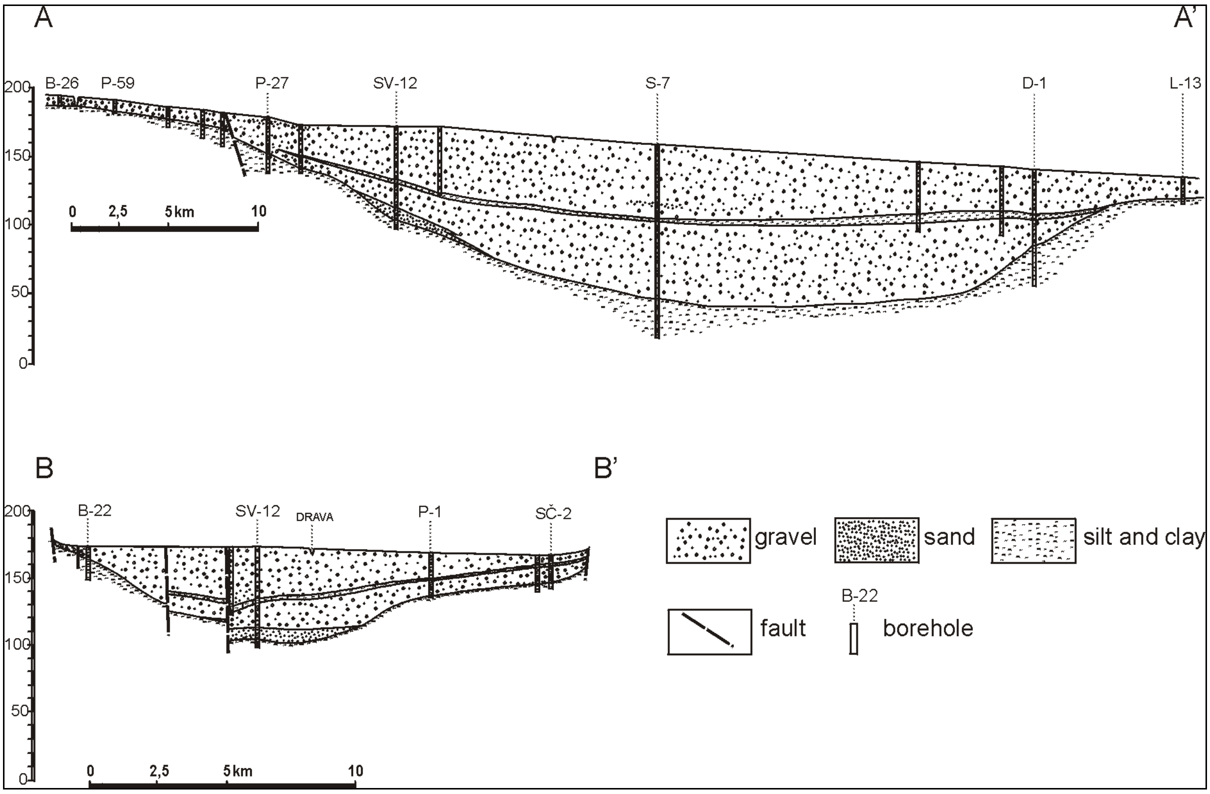

Figure 3. Lithological cross sections

Groundwaters are being recharged by infiltration of rainfall and by induced inflow from the surface watercourses. The infiltration of rainfall is estimated at a level of 10-50% of the average rainfall, which is around 800 mm/yr.

The natural quality of groundwater used to be almost everywhere adequate for the drinking water. In 1970 the nitrate content in the well fields of all communal water-supply systems was as a rule under 3 mg/l. In the following period, the nitrate content was increased everywhere, but it was only in the Varazdin and Bartolovec well fields (Figures 4 and 5) that nitrate content grew significantly over the maximally allowed concentration.

3. Influence of hydro-electrical plants on groundwaters

Three hydroelectric plants were built on the Drava River in the Varazdin basin area. Each has an accumulation lake from which water is transported to the engine room through a channel built in an impermeable embankment. Out of the engine room, the water is transported through a channel that is dug deeply into the aquifer. The marginal conditions of phreatic aquifer were thus significantly altered, because the accumulation lakes have caused recharge of groundwaters and the groundwater level was elevated. On the other side, the drainage channels that were cut into the aquifer have become a line of relatively stable groundwater level, almost horizontal along the entire strip from the engine room to the downstream accumulation. This resulted in strong groundwater drainage downstream of each engine room, which significantly altered earlier natural conditions.

During the planning and construction of hydroelectric plants, the hydraulic conditions after completion of these objects were investigated. With respect to the groundwater, special attention was given to the groundwater leakage through the bottom of the accumulation and under the dam, and also to the consequent increase of the groundwater level. This increase was especially strong immediately after the accumulation was formed for the first time, and was subsequently reduced by construction of the enclosing channels. In a period of time, the accumulation bottom was colmated and the water losses were reduced as well as the influence to groundwater.

Another significant hydraulic disturbance of earlier relations is aquifer drainage through the drainage channels of hydro-electrical plants. When these objects were planned and constructed, this effect was analysed exclusively as a cause of lowering the groundwater level which would dry-out the local private water wells. The mentioned was compensated by construction of a public water-supply system and that is why the first two wells of the Bartolovec well field were built. These two wells are exploiting the water from the upper, phreatic aquifer.

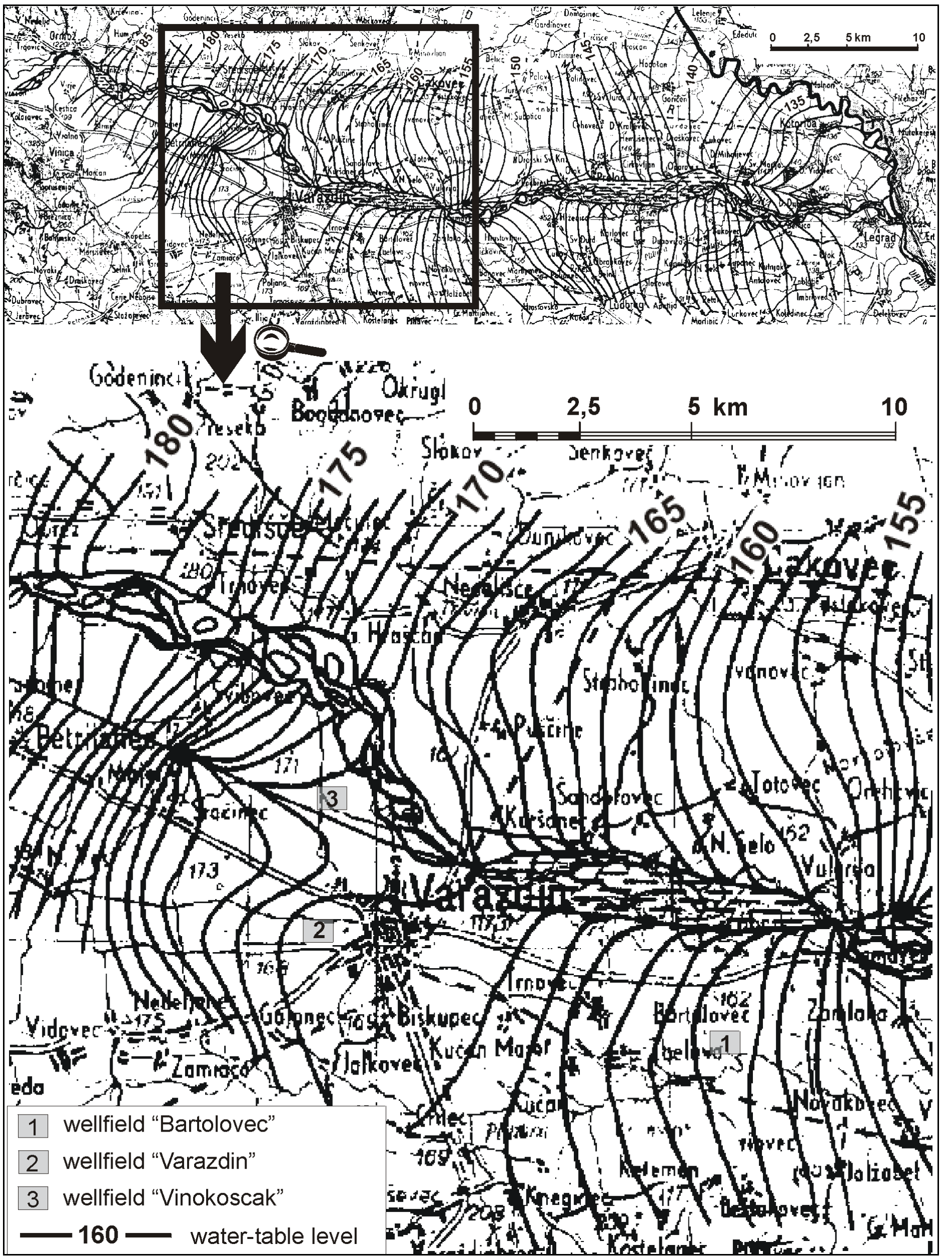

Figure 4. Groundwater contour map.

As already mentioned, when influence of hydroelectric plants to groundwater was originally analysed, the possible alteration of water quality due to changes in marginal conditions of aquifer was not expected. What happened is that the increase in nitrate content (Figure 5) became the principal problem of the water supply after the completion of hydroelectric plants in the vicinity of Varazdin.

4. Discussion

Nitrate content in groundwaters in the region could've been caused either by intensive manuring of agricultural areas or by the excrements that were wasted from numerous poultry farms located upstream of the Varazdin aquifer area. In such conditions, the resulting effect of this type of contamination to the quality of groundwater in well fields used for the water supply of population has to be thoroughly assessed.

At the Varazdin and Bartolovec well fields, which are the most important in the area, an abrupt increase of the nitrate content in water has appeared (Figure 5) exactly in the period of construction of hydro-electrical plants upstream and downstream of Varazdin. How can this coincidence be interpreted? Nitrates do not enter the groundwater as a consequence of inflow of contaminated waters from the surface, because the water of the Drava River and of the accumulation lake as well has small nitrate content (1-3 mg N/l). Actually, in previous natural conditions it was the induced groundwater recharge from the Drava that could've reduced the effects of contamination from agricultural areas. After the drainage channel was constructed, the drainage area of the Varazdin well field was substantially reshaped, which means that it now includes a broader area with intensive agricultural activity. At the same time, the possibility of induced groundwater recharge from the Drava River was excluded. This is the setting in which an alteration of marginal conditions can be observed as an indirect cause for the high nitrate content that was measured in the Varazdin and Bartolovec well fields.

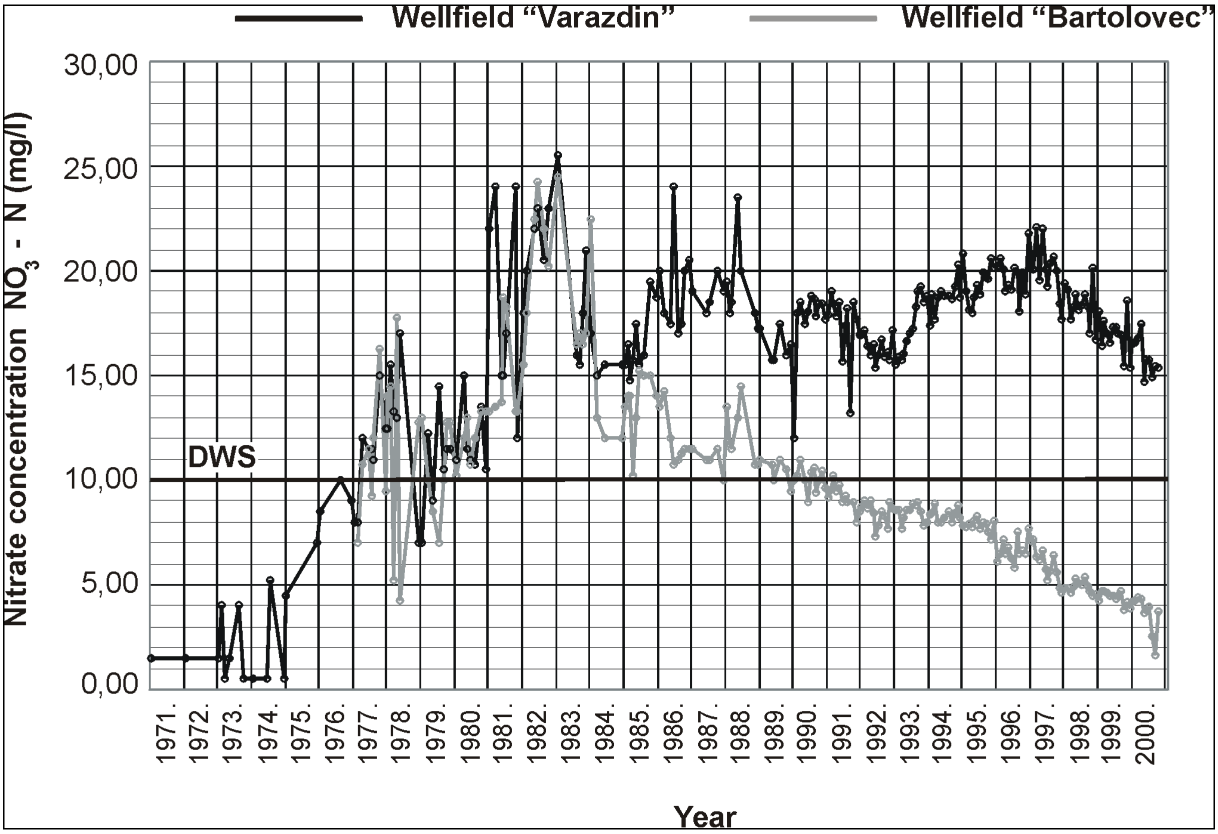

Figure 5. Nitrate concentration in groundwater from 1971 - 2000.

Upon construction of an accumulation upstream of the Bartolovec well field in 1980's, interesting new trends – variations of the nitrate content in groundwater, were observed. The changes of the nitrate content in groundwater from the two well fields started to diverge (Figure 5). Values measured in water from the Varazdin well field continued to oscillate between 15 and 20 mg N/l, while at the Bartolovec field the nitrate content was gradually reduced to the values of under 5 mg N/l (in last years) which means that the water from the two shallow wells of this well field has once more acquired the quality of drinking water. This change can also be attributed to the change of marginal conditions, i.e. to the induced groundwater recharge from the accumulation lake, which has mostly affected the Bartolovec well field.

The data of variations of marginal conditions and of the hydraulic properties of aquifer, as well as exploitation data together with the measured concentration of contaminants (primarily nitrates) enable the construction of a conceptual model. This model is a basis for construction of a flow model of the area, which is to be done during further investigation utilising the GMS software package. The in this way acquired flow field will be used for modelling of the contaminant transport and for delimiting the zone of influence for the existing and future wells of the well fields (EMRL, 2000.)

5. References

Urumovic, K. (1971): O kvartarnom vodonosnom kompleksu na podrucju Varazdina. Geol. vjesnik 24, 183-191, Zagreb.

Urumovic, K., Hlevnjak, B., Prelogovic, E., Mayer. D. (1990): Hidrogeoloski uvjeti varazdinskog vodonosnika. Geol. Vjesnik, 43, 149-158, Zagreb.

EMRL (2000): Groundwater Modeling System 3.1 Tutorials, Brigham Young University-Environmental Modeling Research Laboratory